UCR RoboSub: Design and Implementation of Leviathan

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Abstract -- Leviathan is an autonomous underwater vehicle (AUV) developed by a team of undergraduate students at the University of California, Riverside (UCR). Leviathan is the third vehicle created by the team, and was completely designed and constructed in this season. The vessel is designed to be "future-proof" and extended upon by the team for the next five years. This new vehicle contains foundational competitive capabilities including ease of motion, passive stability, bi-drectional vision, and designated locations for future components. This paper details the design and implementation of Leviathan.

I. INTRODUCTION

The University of California, Riverside's RoboSub Project gives students a unique extracurricular engineering experience building an Autonomous Underwater Vehicle (AUV) to learn and apply multidisciplinary skills, the engineering design process, project management, and practical aspects of engineering not covered in course material. The team is academically diverse, representing students across nearly all engineering disciplines and several physical sciences. This year the UCR RoboSub team designed and constructed a new AUV, Leviathan, and intended to compete in the 2021 RoboSub Competition.

II. COMPETITION STRATEGY

Leviathan is designed for two core features: hydro stability and planar navigation. These features were sought to allow for more complex maneuvers and alignments than our previous AUV, Seadragon. This increased mobility will allow the team to attempt the more complex tasks of the competition, such as the torpedo task and the dropweight task. Leviathan currently is capable of completing the gate task and the buoy task, and is designed to accommodate future subsystems for the torpedo task, drop weight task, and octagon task. The team's focus for this competition was building a strong foundation for Leviathan to complete the basic mission objectives, and for the team to build upon that platform for the 2021 RoboSub competition.

III. DESIGN CREATIVITY

This year the team retired Seadragon, and followed a thorough engineering process for the complete design, construction, and verification of a new AUV, Leviathan. Seadragon had been in iterative use since 2016, and its aging structure and design limitations inhibited its ability to succeed in the tasks that required careful alignment of the AUV, such as the torpedo task and the dropweight task (Figure 1). Leviathan's design draws upon the strengths of Seadragon, addresses Seadragon's weaknesses, and features forward-looking design elements.

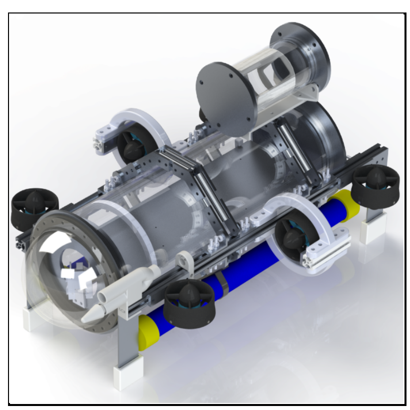

Fig 1. 2020 Design Render of Seadragon

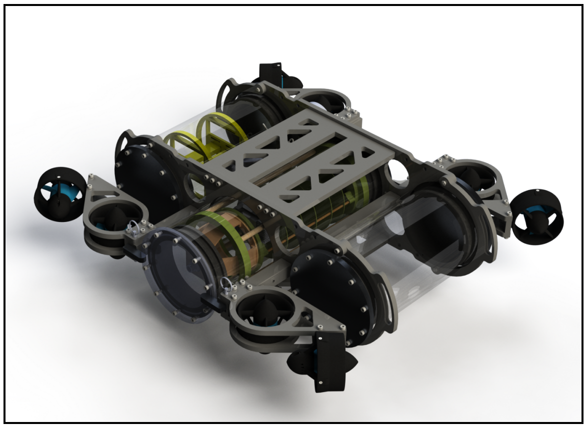

Fig 2. 2021 Design Render of Leviathan

The design changes can be broken into Mechanical, Electrical and Software subsystems.

A. *Mechanical Design*

Leviathan was designed around three cylinders and eight thrusters. The geometry of the AUV is square-like for easier alignment of the center of gravity and center of buoyancy, and the team sought to optimize Leviathan being both compact and maintainable (Figure 2).

1) *Machining*

The AUV was designed for almost every metal part to be laser cut from a 1cm-thick aluminum plate. The parts were designed to require as minimum post-machining as possible and share uniform fasteners. Post-machining included threading holes and drilling through on some parts. 3D printed guides were made to help drill the holes at the correct location.

2) *Electronics Chassis*

The three cylinder design was intended for housing electronics, batteries, and an undesignated third subsystem. The center cylinder holds most of the electronics, including the printed circuit boards (PCBs), cameras, and computers. One of the side cylinders contains the battery scaffold assembly. The opposite cylinder presently serves as a counterweight for the battery, but will house future sub-systems for the torpedoes, drop weights, or pinger locator. The center cylinder is positioned as forward as possible to maximize a front camera's field of view, and to leave room for a bottom camera to see without obstruction.

1060-T Aluminum was chosen for the frame because of its ease of manufacturing, corrosion resistance, and effectiveness as a heat sink. The endplates feature a double o-ring flange with o-rings made from stock rubber cording. The grooves were dimensioned according to published SAE o-ring standards [1]. The flanges were intended to be manufactured by the team, however were instead purchased to ensure consistent machining accuracy.

3) *Motors and Configuration*

The motors and their configuration allow for all axes of translation (x, y, z) and all axes of rotation (yaw, pitch, roll), for a total of 6 degrees of freedom. The presence of four depth thrusters allows for steady vertical motion and the four diagonal thrusters along the center of mass allow for horizontal planar movement. The AUV is designed such that the center of mass lies at the geometric center of the top-down square profile, with the thrusters positioned accordingly to minimize undesired moments of inertia.

As shown in Figure 3, in order to create a forward motion the side thrusters will produce a combination of vertical as well as horizontal force propulsions. The horizontal components will eventually be negligible considering the propulsion vectors will be opposite in direction but equivalent in magnitude. As for the vertical components, the side thrusters' vectors will point in the same direction resulting in a combination of vertical propulsion forces.

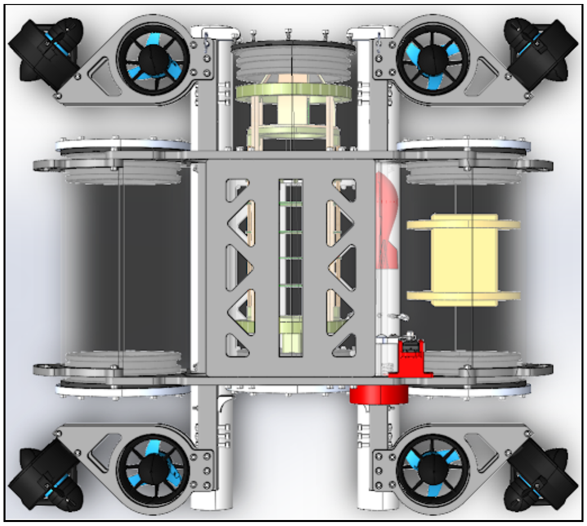

Fig 3. Top View of the Leviathan Assembly

4) Electronics Rack

The purpose of the electronics rack is to maintain all of the electronic components of the Leviathan in a safe and organized manner. The location of the rack is inside the main tube. The rack assembly consists generally of a push-pull assembly as shown in Figure 4. This design facilitates the process of removing electronic components for the Electrical team during mock obstacles testing.

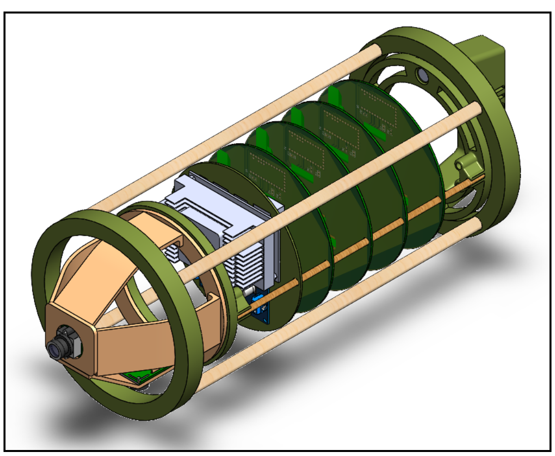

Fig 4. Isometric View of the Electronics Rack

B. Electrical Design

For the 2021 competition we assembled and tested printed circuit boards for the electronics. We unit tested our hardware with our power based components, microcontroller (MCU) boards, and a Nvidia Jetson TX2 module stationed on the Orbitty carrier board.

1) Hardware components

Our electrical design consists of four circular PCBs, which includes a peripheral power distribution board (PDB), peripherals board, thruster power distribution board, and Jetson power control board. They integrate with:

- (2) Teensy 3.2 MCUs
- Jetson TX2 computer module board
- Bar30 Pressure sensor
- 12V solenoid valve
- LED strip
- Altitude and Heading Reference System (AHRS)
- (2) Cameras
- (8)Electronic speed controllers (ESCs) connected to (8) thrusters.

The design is powered by two 14.8V LiPo batteries, of which one's voltage is stepped down by the peripherals PDB to power the MCUs and their integrated hardware. The other battery connects to the ESCs to power the thrusters.

2) Printed Circuit Board design

a) MCU/Peripherals PDB

This PCB has an array of buck converters that receives a 14.8V input and steps the voltage down to 5V and 12V to provide peripheral power for the MCUs and other hardware.

b) Task Board

This PCB holds one teensy 3.2 MCU. It controls all auxiliaries. The led strip and LCD screen are used to relay information from the MCUs and Jetson to a screen. The solenoids are used to launch 2 torpedoes at a target. This MCU also communicates to the thruster board via USART and to the Jetson through ROS.

c) Thruster PDB

This PCB houses our other teensy 3.2 MCU. It distributes power to the thrusters, sends PWM signals to the ESCs that control the thrusters and also contains automotive grade MOSFETs that are used for a kill switch in conjunction with a magnetic reed switch. The teensy communicates with the Task board teensy through USART.

d) Jetson PCB

This PCB is used as a safety net for the Jetson TX2 module, it has a short-circuit protection circuit and a polarity protection circuit to prevent the Jetson from being powered incorrectly. Circuits were also designed allowing the AUV operator to power on and restart the Jetson CPU from outside the AUV.

C. *Software Design*

For the 2021 competition, the team integrated computer vision into the software system. Robot Operating System (ROS) was utilized for message-passing between systems. The software was written in C/C++ and Python.

1) Behavior

The mission planner was implemented as a complex state machine. A master state machine controls which competition task to perform next. This decision is based on information from the computer vision system and previously completed tasks. Once a competition task is enabled it will move through each of its states, performing a simple action in each (move forward, rotate, change depth, or shoot torpedo). Once a task is completed, it sends a message to the master state machine to move on to the next task. Messages between state machines, computer vision, and the motor control system are passed via the ROS publisher/subscriber system.

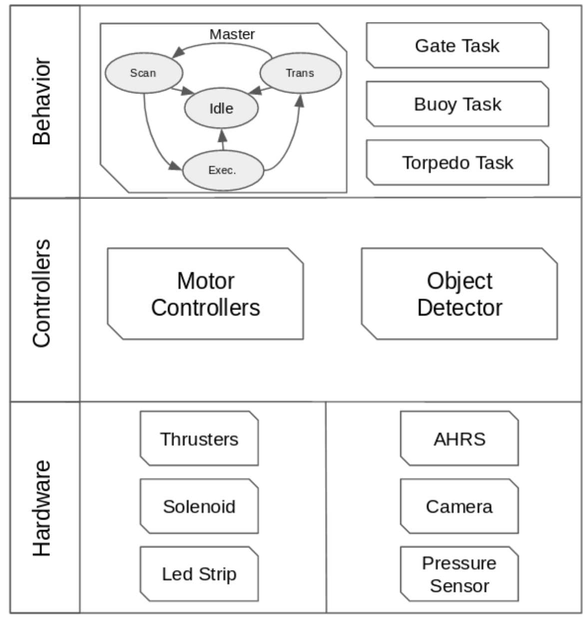

Fig 5. 2021 Software High Level Diagram

2) Computer Vision

This year the software team focused on implementing computer vision as it is critical in completing most of the competition's tasks. To achieve this, we utilized an existing deep learning framework called Darknet, in combination with the OpenCV library for image processing. We collected hundreds of images, differing in rotational and translational information, for each object that we wanted to detect. For this year, we trained a deep neural network to recognize the gate and the various images shown on the competition's obstacles. To do this, we trained our own model based off the "You Only Look Once" yoloV3-tiny model. This allowed us to get a sufficient frame rate and high enough accuracy for real time object detection. Of course, training this network involved the use of a video card for GPU acceleration, for which we used the CUDA toolkit.

3) Control System

Leviathan utilizes an AHRS (attitude and heading reference system) and depth sensor to provide feedback to several PID controllers. These elementary controllers allow the submarine to maintain its heading and depth. The PID controllers integrate with ROS for value storage and communication with other processes.

3) GUI

We create a Graphical User Interface (GUI) to receive telemetry from the submarine to interpret and display the data in a meaningful manner. In addition, the GUI will allow us to send precise commands to the submarine for execution.

IV. EXPERIMENTAL RESULTS

1) Waterproofing: The waterproofing method is broken into several phases:

I) After the core frame and chassis improvements were done, we test for leaks by submerging the submarine at 12ft depth for thirty minutes.

II) After integrating the electrical systems, we repeat the "sink test" to ensure that the penetrators passing the electronics cables through the endcaps are watertight. To determine any leak locations of the chassis, paper towels are placed along the inside of the acrylic cylinders. When wet, the towels became noticeably darker, indicating a leak.

On February 6th, 2021, a water-test of the end-cap seals was successfully performed to report no water penetrations on the flange o-rings. Most importantly, safety regulations were also considered due to the COVID-19 pandemic.

2) *Water Testing:* In-water software testing includes the following:

I) Connecting an onshore laptop to the electronics in the chassis, and testing the electronics with manual thruster control to ensure the power distribution boards are working properly.

II) PID tuning to ensure the motors and on-board computer have correct feedback control parameters.

III) Using constructed mock-competition obstacles to test the autonomous mission planning and feedback control systems.

3) PCB Testing: PCB testing consists of the following:

I) Unit stress testing each PCB's functionality with border cases to ensure no abnormal behavior and to ensure expected results.

II) Unit testing each PCB with long duration periods to examine the electronics' durability and heat generation due to longer-than-anticipated operation.

III) Multiple voltage inputs are tested to ensure the power distribution boards work as intended in failure modes.

4) Software Testing

Before water-testing, we use unit tests and the Gazebo sandbox simulator to examine the reliability of the software separate from the mechanical and electrical parts. Once all unit tests for the state machines pass successfully, they are tested on the physical submarine. When the mechanical, electrical, and software systems pass all their own tests and are deemed to be fully functional, the physical submarine is placed into local swimming pools for live water testing. At this time, the software will be running while tethered over an Ethernet cable to a laptop, so that telemetry can be monitored, and commands can be sent during the live water test.

5) Mechanical Testing

In order to simulate the reliability of the CO_2 Torpedo Launcher mechanism, a test stand was designed to analyze the fatigue life of the springs (puncturing force) as well as the effectiveness of the torpedo aerodynamic design. As shown in Figure 6, the ring CAD with the eye-bolts inserted simulates the friction force from the acrylic tube inner diameter. Similarly, the rotating paddle can be compared to the servo mount assembly that releases the puncture plate ultimately leading to the release of the angled torpedo by the propulsion system (12g CO_2 cartridge).

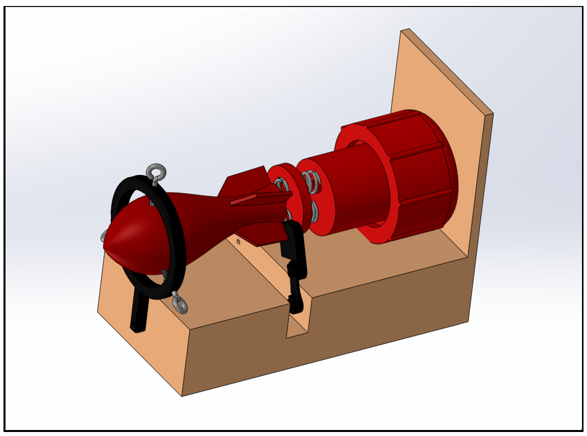

Fig 6. Test stand for the torpedo launcher prototype

V. ACKNOWLEDGEMENTS

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- Industrial Metal Supply
- JLCPCB
- UCR's Department of Electrical and Computer Engineering
- UCR's MESA Schools Program
- UCR's IEEE Student Chapter
- UCR's ASME Student Chapter

VI. REFERENCES

[1] "Cross Section & Groove Design Data." O-Ring Cross Section & O-Ring Groove Design Data. N.p., n.d. Web. 21 June 2017.

Appendix A: Component Specifications

In the past, a detailed list of components constituted the bulk of many paper submissions. This practice is discouraged as it distracts from the underlying strategic thinking, system engineering decisions, or novel contributions. For the record, teams should list the components actually used in the vehicle in the table below.

Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control	The Home Depot	PVC Sch. 40 DWV Pipe	1-½ in. x 24 in.	$7.12
Frame	Industrial Metal Supply	Aluminum T1060	38 in. x 35 in.	$62
Waterproof Housing	Tap Plastics	Acrylic Cylinder	6.5”OD x 6”ID (1) 17in. length (2) 11.75in. length	$80
Waterproof Connectors	Fisher Connectors			Reused
Thrusters	Blue Robotics	T100 / T200	Purchased 2 T200	$362
Motor Control	Afro ESC			Reused
High Level Control		N/A		
Actuators		N/A		
Propellers		N/A		
Battery	Pulse Battery		14.8V, 35C, 6600mAh	$94
Converter	(homemade)			~$35
Regulator	(homemade)			~$20
CPU	Nvidia Jetson TX2			$0 (borrowed from RoboNation)
Internal Comm Network	Open Robotics	Robot Operating System		$0
External Comm Network		N/A		

Programming Language 1	Python		For state machine and general com	
Programming Language 2	C		For microcontrollers	
Compass	MyAHRS+			Reused
IMU	MyAHRS+			
DVL		N/A		
Cameras				Reused
Hydrophones		N/A		
Manipulator		N/A		
Algorithms: vision			Neural network based on DarkNet	
Algorithms: acoustics		N/A		
Algorithms: localization/ mapping		N/A		
Algorithms: Autonomy			State machines	
Open Source Software			OpenCV, ROS, ImgLabel	
Team Size			20	
HW/SW expertise ratio			HW: 70% SW: 30%	
Testing Time: Simulation			120 hours	
Simulation Software	Open Robotics	Gazebo Version 9.0.0		$0
Testing Time: in-water			0 hours	

Appendix B: Outreach Activities

UCR RoboSub has worked closely with the MESA program at UCR. During the 2019-2020 academic year RoboSub members attended MESA events, where they presented the submarine and discussed the benefits of working in a team STEM project. Many members also volunteered to be judges for the 2020 SeaPerch event.